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A review of Additive Manufacturing technology and Cost Estimation techniques for the defence sector

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ABSTRACT

"Additive Manufacturing" (AM) is a promising technology which will provide major advantages to Defence Support Service providers, given its ability of delocalised manufacturing near the point of use. The technology is gaining increasing interest due to its disruptive potential. AM groups together a wide range of different approaches which have the ability to convert a 3D file into a physical product by depositing layer upon layer of material. AM is still under development and considered an immature technology. This immaturity provides high level of uncertainty around key indicators such as time and cost. These indicators represent also key decision variables to evaluate AM and compare it with traditional manufacturing. This review paper represents an investigation of existing knowledge on AM and aims to present to the reader the various AM approaches with a detailed focus on the most applicable technologies to Defence Support Services. The paper is structured as follows, firstly the various technologies of AM and their economic aspects are presented, secondly the cost modelling techniques are investigated and finally a discussion is carried out. The contribution of this paper is to present to Defence Support Service stakeholders the various AM technologies and cost modelling techniques for measuring the product or service cost.

Introduction

Defence Support Service providers operate in safety and mission critical environments and are responsible for delivering integrated product and service solutions. These providers are responsible for maintaining one or more complex engineering systems under performance based contracts, which are typically measured with component, equipment or system availability. "Additive Manufacturing" (AM) is a promising technology, which builds components by adding layers of material and provides the ability to produce complex geometries without the need of extensive manufacturing systems. Due to its versatility and relative compactness, various Defence Support Service providers operating in the Defence industry are exploiting the opportunity to provide Platforms with AM capability. The main example is the USS Essex which has applied AM for printing drones and disposable medical supplies [1]. Having AM capability on a platform might provide advantages in mission critical environments with disrupted supply chains. To evaluate the technology, the costs and delivery time have to be evaluated. Given a wide range of AM technologies available this review paper focus on presenting the various approaches and outline the differences. Moreover, as cost represents the main critical variable, cost modelling techniques are presented and compared allowing the reader to choose the most appropriate one for this application.

Section "AM research effort and journal selection" provides an overview of the research efforts on AM. Section "Additive Manufacturing" introduces AM technology and its constituent process methodologies. Section "Cost modelling techniques" covers existing cost modelling techniques and outlines the most suitable technique for AM product Cost Estimation. Section "Cost Modelling for Additive Manufacturing" outlines economic aspects of AM and compares them with traditional manufacturing techniques. In Section "Economics of Additive Manufacturing" a

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discussion is carried out to justify the selection of the technology and cost modelling techniques. Finally Section “Discussion” concludes the paper and summarises what has been investigated.

AM research effort and journal selection

To assess the current research on AM, an analysis of publications has been carried out on the SCOPUS database using “Additive Manufacturing”, “Cost Modelling”, “Cost Estimation”, and “Support Services” as keywords. A total of 2300 publications have been published during the period between 1997 and 2017. The review is based on a lower number of publications which has been selected due to their relevance to the research scope involving, Support Services, defence applications,

Most publications were conference and journal paper. Fig. 1 outlines the research published per year. This graph is featured by two periods. The first one between 1997 and 2009 in which publications were relatively steady, the second period between 2009 and 2014 in which Additive Manufacturing research interest has grown dramatically from 69 to 873 publications. This is mainly a consequences of a growing awareness of governments, research institutes and companies on AM benefits.

Loughborough University is leading the scene with a total of 92 publications, followed by the University of Texas El Paso with 65 publications and the Katholicke Universitaet Leuven with 54. Another interesting finding is the publication by country; United States is leading the scene with 961 publications followed by the United Kingdom with 300 and Germany with 281. If the analysis is tailored to “Cost Modelling for Additive Manufacturing” the main Institutions which have mostly contributed to the research effort on estimating the costs of AM are: Loughborough University with 4 journal papers, Nottingham University with 1 conference paper for “Selective Laser Melting” (SLM), Cranfield University with 2 PhD thesis for “Wire + Arc Additive Manufacturing” (WAAM). Another important contribution is made by the Universidad Politecnica de Catalonia which published a Neural Network model for time generation for Selective Laser Melting. Finally, the Naval Postgraduate School of California conducted research on AM implementation in US Navy platforms for supporting the systems with printing spares. Given the large amount of published journals on Additive Manufacturing and related cost modelling techniques, a selection of information has been carried out. Firstly experts from the “Welding Engineering and Laser processing centre” of Cranfield have been identified and interviewed (Colegrove, Martina and Ding). Secondly the experts have provided the most relevant references of journals to be reviewed. Moreover references of the journals provided have been reviewed and included.

Additive Manufacturing

Ivanova et al. [2] defines “Additive Manufacturing” (AM) as a group of emerging and promising technologies that create an object by adding material bottom-up. AM enables rapid conversion of CAD files into physical products by merging layer upon layer of heated material [3]. It is defined as the “process of joining materials to make objects from three-dimensional (3D) model data, usually layer by layer, as opposed to subtractive manufacturing methodology” [4]. As stated by Gao et al. [5] the term “Additive Manufacturing” was ultimately chosen by the ASTM F42 committee as it clearly distinguishes the processes from subtractive manufacturing techniques wherein material is removed from a workpiece. As outlined by Ivanova et al. [2], AM technology is a relatively simple process compared to traditional manufacturing which is labour intensive, requires more resources and complex processes such as machining, forging and moulding.

As outlined in Fig. 2 the inputs of AM are raw materials, supports and utilities. On the control side there is a CAD file which contains the geometry of the object and the parameters which can get up to 150 different variables. Parameters play a crucial role in the process as they have a strong incidence on object quality. On the mechanism side there is the substrate which is the plate on which the object will be grown. The substrate is usually made of the same material which will be deposited and is recyclable. The ‘*American Society of Testing and Materials*’ (ASTM), issued in 2013 a standard for AM technologies. The aim of the standard is to group together current AM process methodologies. The result is a group

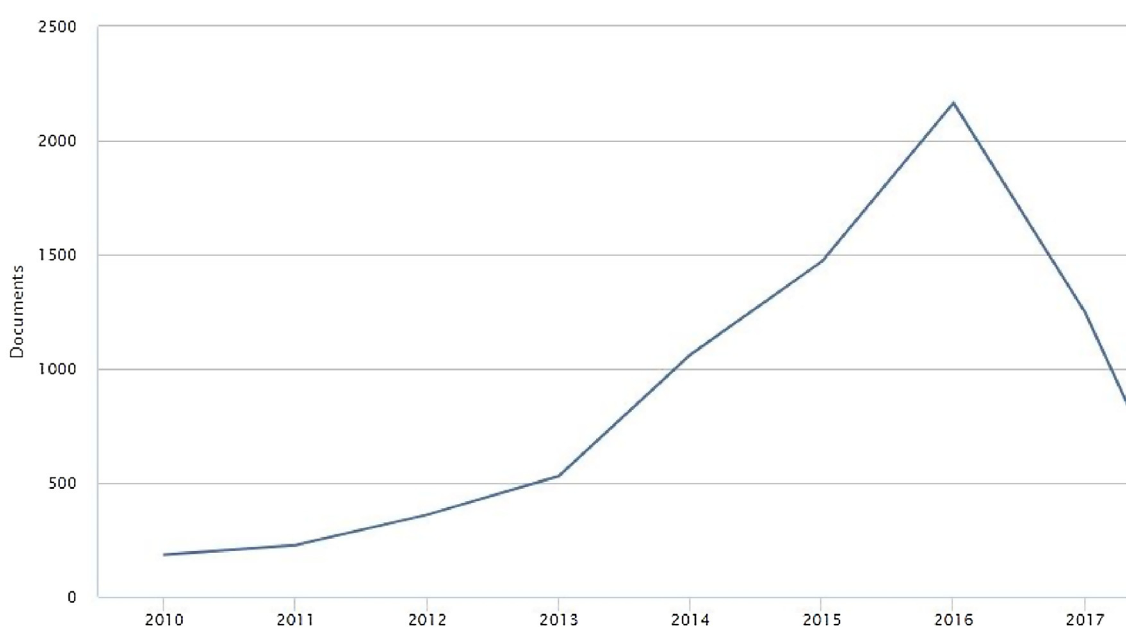

Fig. 1. AM publication per year.

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